TECHNICAL REPORT NO. LWL-CR-05C71

SNOW STABILIZATION TECHNIQUES FOR HELICOPTER LANDINGS

Final Report
Contract No. DAAD05-68-C-0283

By
Franklin Institute Research Laboratories
Benjamin Franklin Parkway
Philadelphia, Pennsylvania 19103

September 1971

U. S. ARMY LAND WARFARE LABORATORY
Aberdeen Proving Ground, Maryland 21005

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ABSTRACT

This report describes the result of a feasibility study to investigate surface stabilization of snow by chemical treatment to eliminate reduced visibility created by helicopter down wash on landing and take-off. Of the candidate methods evaluated, sintering of the snow by methanol appeared the most promising method. Polyurethane foam and snow-reactive metal alkyls, while promising, would require more development work.

FORWARD

The work described in this report was performed under work assignment numbers 3 and 6 of contract number DAAD05-70-C-0389. The Franklin Institute Research Laboratories wishes to acknowledge the technical guidance given by Mr. Stephen Clancy of the Applied Chemistry Branch, U. S. Army Land Warfare Laboratory who was Technical Supervisor for this task.

The principal engineer on the project at FIRL was Dr. Francis Cooke, Manager of the Metallurgy Laboratory, Materials Science and Engineering Department. Other major FIRL technical contributors included William B. Tarpley of the Materials Science and Engineering Department, and Peter S. Francis of the Chemistry Department.

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1. FEASIBILITY STUDY

1.1 Introduction

Air mobility essential for military operations in snow covered environments is seriously hampered by blowing snow occurring when helicopters take-off and land. The transition period which occurs when helicopters leave snow covered terrain to become airborne, and vice versa for landing, is highly critical. Safety dictates that the pilots vision and depth perception must be unimpaired. Mechanical aids and instruments have materially assisted in take-off and landing operations, but greater assurance of visibility is needed. A clear view of the surface in front and below the aircraft is required. Blowing snow, occurring when aircraft take-off and land, is a serious safety hazard, and is verified by aircraft accident statistics. A means for rapid stabilization of snow that will, in a minimum of time, provide and maintain (for moderate time periods) adequate localized near-surface visibility for the operation of aircraft is required.

The Franklin Institute Research Laboratories was directed by USALWL under work assignment numbers 3 and 6 to investigate the feasibility of surface stabilization of snow to eliminate reduced visibility created by helicopter downwash on landing and take-off. The system must be logistically and economically feasible, be resistant to helicopter downwash air speeds up to 120 miles per hour wind velocity for prolonged periods, be non-toxic and non-corrosive, desirably be capable of air dissemination and be effective at temperatures as low as -40°C.

The feasibility study was divided into two main phases: Phase I, a laboratory evaluation of candidate snow stabilization methods (Assignment No. 3) and Phase II, a field evaluation of the most promising snow stabilization methods developed in the laboratory evaluation (Work Assignment No. 6). Included in Phase I was a literature search, contact with government agencies who have conducted studies in snow and soil stabilization, an analytical evaluation of candidate methods, and a laboratory evaluation of the more promising candidate methods utilizing simulated powder snow. Phase II, the field evaluation, included preliminary field evaluations conducted in close proximity to the FIRL in Philadelphia and followed by field evaluation in upstate New York near the Canadian border. The full scale field evaluation consisted of testing eight large (730 sq. ft.) snow fields representing two types of snow and determining the resistance to blowing and penetration. A second field test attempted at the suggestion of the sponsor representative on the first of March had to be aborted because of unsuitable weather.

1.2 Phase I - Laboratory Evaluation

1.2.1 Literature Search

Although primary effort in the literature search was directed towards snow stabilization, a review was also conducted into the stabilization of other "particulate" surfaces, especially soils. A complete bibliography listing of the reports reviewed and evaluated is given in Appendix A of this report.

Contacts were also established with personnel at the Cold Regions

Research Laboratories, the Aero-Propulsion Laboratories at Wright-Patterson Air Force Base, The Army Engineer Waterways Experimental Station and the University of Washington where much of the avalanche suppression work was performed. Actual visits were made to the Aero Propulsion Laboratory and the Waterways Experimental Station.

The first trip was made to Aero-Propulsion Laboratory, WPAFB, Dayton, Ohio, since most of the Air Force effort in developing techniques to stabilize "dirt" runways was centered in this group up to two years ago. This responsibility was then taken over by the A.F. Civil Engineering Group in San Antonio but little further work has deen done since then.

The persons visited were Mr. Max Sheets and Mr. Richard Bankhead. They discussed their experiences with soil stabilization which was mostly resin bonding of fiberglas mats on the surface, and supplied us with a number of reports on their work. The main problem they had using their techniques in S.E.A. was storage of the catalyst which should have been kept below some critical temperature. They had no problems with the troops either in training or actual deployment, but they also admitted they used highly motivated men with good mechanical aptitude and general mechanical training, e.g. aircraft mechanics.

On at least one occasion they repaired a large section of runway in the winter in the presence of snow. This is described in one of the reports supplied (AFAPL TR 69-60, July 69). Also they routinely deployed directly over wet turf and grass at temperatures down to 50°F.

Their use of latex material was essentially a limited test of painting ground surface with water base paint (colloidal latex in water) that

happened to be available. It was judged ineffective as a dust suppressor because it was easily degraded by people walking on it.

They also found that a continuous strand fiberglas sprayed in place was stronger than using prefelted mats of chopped fibers provided the continuous stranded mat was put down very uniformly. This proved difficult to do in the field so they went to the prefelted mats.

The method for quantitative testing of the load bearing capacity of surfaces was to cut out large bend test specimens for laboratory evaluation or to use the standard civil engineering penetrating device mounted on a truck bumper to determine the California Bearing Ratio[1] for field tests.

Personnel also visited the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, to review their work on dust suppression and determine if it could be adapted to the snow stabilization problem. Information was collected on field and laboratory wind testing as well as techniques for consolidation of dusts. Their successful systems are based on deploying loose chopped fiberglas or woven mats over a prepared surface and binding the system to the top layers of soil with a water-based polymer latex. Minimum useful treatment weight amounts to about three pounds per square yard. "Cure" time may be several hours.

The Vicksburg group further advised that descending helicopters will start dust clouds at distances of about four rotor diameters above the ground. They described a helicopter approach technique that may permit close approach to the ground - the aircraft could cruise forward over the ground at altitutes as low as ten feet, moving ahead of the snow cloud.

It may be very possible for the crew to treat the snow surface during such a low pass and then come around and land on that surface.

1.2.2 Candidate Snow Stabilization Approaches

1.2.2.1 Approaches Considered

In addition to the five candidate methods suggested in the scope of work for work assignment number 3, six other candidate approaches were developed as a result of either the literature search, discussions with other agencies or internal suggestions generated after in-depth evaluation of the basic problem. In the following paragraphs, each of the eleven approaches are reviewed and analytically considered. Table I.

1. Accelerated Sintering

Accelerated sintering may be accomplished either by applying liquids to melt or dissolve the snow particles which refreeze into a more stable surface, or by adding dopants which can accelerate the sintering of the individual snow particles into a more stable surface by solid state diffusion or by vapor phase transport.

In the former approach, materials such as methanol and ethylene glycol/water mixtures appear promising. Spraying these materials on snow would initially cause melting of the snow crystals and particles. A slush would be formed which would then either refreeze into a hard ice surface or remain a heavy slushy fluid. In either case, the fine snow texture would be appreciably modified and snow stabilization accomplished.

The later approach using dopants was based on accelerated sintering occurring by means of solid state diffusion or vapor transport

Table I

SUMMARY POTENTIAL STABILIZATION METHODS

	Stabilization Method	Principal of Operation	Estimated Quantity Required wgt/200 ft^2	Possible Advantages	Possible Disadvantages	Dissemination Method: Aircraft: Direct Application	Dissemination Method: Aircraft: Air Emplaced Device	Dissemination Method: Ground Applied
1.	Doping (Sintering)	Doping the snow with selected materials causes accelerated sintering of the snow by either solid state diffusion or vapor transport.	30 to 40 pounds	1. Readily dispersible 2. Good efficiency	1. Not very rapid unless heated 2. Corrosion (F-)	Yes	Yes	Yes
2.	Water	Heated water is sprayed directly on the snow surface causing the flakes to sinter and form a crust.	150 to 300 pounds	1. Readily available 2. No mixing 3. Non hazardous 4. Non flammable	1. Water will freeze unless heated or treated with antifreeze 2. Large quantity may be required	?	Yes	Yes
3.	Octyl Alcohols	Octyl alcohol combines the doping and profriction phenomenon.	25 to 50 pounds (plus solvent)	1. Stabilization principal demonstrated in avalanche control studies	Requires considerable time to react with snow.	Yes	Yes	Yes
4.	Tween 21	Profriction materials are compounds which when added to snow increase the particle flake attractions and promote improved adhesion.	10 to 20 pounds dissolved in 500 pounds of solvent	1. Readily dispensable 2. Low cost 3. Solvent also promotes sintering	1. Requires considerable time to react with snow 2. Freezing without antifreeze	Yes	Yes	Yes
5.	Cab-O-Sil	" "	Possibly small weight - large volume	1. Solid powder	1. Powdery - must be used as a solution/suspension (erosiveness, bulk logistics)	?	?	Yes
6.	Span 20	" "	10 to 20 pounds dissolved in 500 pounds of solvent	1. Readily dispensible 2. Low cost	1. Requires considerable time to react with snow 2. Freezing without antifreeze	Yes	Yes	Yes

Table I (Cont.)

Stabilization Method	Principal of Operation	Estimated Quantity Required wgt/200 ft^2	Possible Advantages	Possible Disadvantages	Dissemination Method: Aircraft: Direct Application	Dissemination Method: Aircraft: Air Emplaced Device	Dissemination Method: Ground Applied
7. Low Expansion Foams	Low expansion foam components sprayed on snow where they expand into a rigidly attached film having a minimum thickness of 1/10 to 1/8 of an inch. Expansion ratios range from 30:1 to 60:1.	30 to 50 pounds	1. Semi-rigid mat which completely covers the surface.	1. Expansion retarded at low temperature 2. Covering must be uniform or wind will get under coating and lift off snow.	?	Yes	Yes
8. High Expansion Foams	Same as above except minimum thickness in the order of several inches. The expansion ratios are generally greater than 1000:1	30 to 50 pounds	1. Foam layer several inches thick covers landing area.	Same as above plus (1) wind might break up foam more readily and blow away (2) all practical systems are water based.	?	Yes	Yes
9. Fibers	Heated fibers are dispersed over snow and lock the loose flakes into a thin mat by melting refreezing the flake contiguous to the fibers.	12 to 60 pounds (+ heat)	1. Easily dispersed 2. Excellent efficiency 3. Quick	1. Aerial dispersion will cause the fibers to cool too rapidly before reaching snow. 2. Heat required	No	Yes	Yes
10. Ultra thin Films	Polymeric/colloidal particles suspended in non-aqueous solvents are dispersed on the snow and form films when the solvent evaporates or disperses into the snow.	12 to 25 pounds	1. Ease of application 2. Besides film, some sintering might occur due to solvent/snow interaction	1. Adhesion with the snow might not be strong enough (especially edges) 2. Uniformity problems	Yes	Yes	Yes
11. Organometallic	Pyrophoric liquids on exposure to air/water/snow generate considerable heat. The liquid dispersed on snow would cause flakes to melt and upon refreezing form a thick crust.	20 to 50 pounds	1. No ancillary heating 2. Spray readily 3. Reacts with snow generating heat 4. Quick	1. Flammable - requires a fire retardant 2. Potential handling problems	?	Yes	Yes

mechanisms. The dopants should be such as to lower the bonding energies in the ice crystal lattice. It was expected that the most potent dopant for this purpose would be fluoride ion. Fluoride ion has the disadvantage that its compounds are highly corrosive and toxic. Most of the experiments on the effect of F^- on mechanical and electrical properties of ice employ HF as NH_4F. The advantage of this system is that only small concentrations of F^- ion are required and hence it would be logistically favorable. The disadvantage is that, at best, dopant sintering is a slow process.

Since the sintering mechanisms for ice are exceedingly complicated and are only poorly understood[(2)], the definitive evaluation of this concept was to be done experimentally. The experiment consisted of spraying the surface of a number of snow samples with F^- solution of various concentrations and compositions. The time required for sintering to produce a mechanically detectable crust was determined.

2. Water

For purposes of comparison, the idea of spraying water on the surface of the snow was considered. The water could not be delivered hotter than the boiling point and in fact considerable heat would have to be supplied during transport to prevent freezing. Alternatively some anti-freeze could be added but care would have to be taken to insure that the solution would freeze after dispersion. In either case, it is logistically unrealistic to expect to deliver any significant amount of heat to the snow by way of a water spray. The best that could be hoped for would be to infiltrate the surface of the snow with liquid water

before the liquid water freezes. If a 1/16" layer of water were deposited and allowed to infiltrate the snow to form an 1/8" slush crust, a reasonable estimate would be that the amount of water required would be ten times the weight of organometallic required to freeze a similar crust.

3. <u>Surface Active Agents</u>

E. LaChapelle and R. Stillman at the University of Washington looked into chemical modification of snow by chemical means in their studies (1966) of avalanche control.[3] They found that trace amounts of long chain hydrocarbon molecules could alter or inhibit the growth of ice crystals (depth hoar). Octanol, benzaldehyde and n-heptaldehyde were used in trace amounts to inhibit ice crystal growth by sublimation. Professor LaChapelle presumed the organic molecules attached themselves to particular sites on the ice crystal and blocked the attachment of water vapor molecules to the crystal in certain directions of growth. It was found that octanol markedly accelerated the growth of ice crystals but that the crystals were much more fragile than natural hoar crystals. It should be noted, however, that even in this case 16 days were required to develop crystals which were 3 to 4 mm. long. It is unlikely that this phenomenon which is similar to the dopant assisted sintering concept, can be accelerated sufficiently to make it practicable for the purposes of our program.

Profriction Agents

In early work by FIRL personnel on textile fiber spinning, it was found that certain surfactants when applied to cotton fibers increased the spinning friction. Accordingly, these, or solid anti-slip materials

might decrease snowflake inter particle slip and reduce blowing.

4. "Span" surface agents are partial esters of common fatty acids and hexitol anhydrides derived from sorbitol that have hydrophillic and lipophillic nature within the same molecule. The hydrophillic character is produced by free hydroxyl or oxyethylene groups. The lipophillic portion is found in the long hydrocarbon chain of the fatty acids or alcohols.

5. "Tween"

"Tweens" are derived from the "Spans" by adding polyoxyethylene chains to the non-esterified hydroxyls. The Tweens are generally more hydrophillic and water soluble than the Spans.

A balance between the hydrophillic and lipophillic character to make an emulsion can be estimated from the chemical composition. The supplier* used by FIRL in this program uses an "HLB" (hydrophile/lipophile balance) number (a scale of 0 to 20) to classify these compounds and appropriate mixtures of more than one material can produce a range of combinations that are very oil soluble to those that are very water soluble. Low HLB numbers are oil loving types and large numbers associated with hydrophillic types. The Spans and Tweens that are strongly hydrophillic are of most interest to our application to snow.

In addition to selecting the Span and Tween with the higher HLB numbers, they must also have a suitable viscosity for use at low temperatures, be soluble or at least dispensible in aqueous, water-methanol or

*Atlas Chemical Co. - Use of their products was a convenience and does not imply indorsement by FIRL of the sponsor.

water-ethylene glycol solution (inexpensive antifreeze solutions) and preferably have high flash and fire points. On this basis Span 20 and Tween 21 were selected and obtained for preliminary trials. Some of their properties are listed below:

Compound	Sorbitan Monolaurate	Polyoxyethylene Sorbitan Monolaurate
HLB	8.6	13.3
form at 25°C	oily liquid	oily liquid
viscosity (Cp. at 25°C)	3500 - 5000	350 - 550
specific gravity	1.00 - 1.06	1.05 - 1.10
flash pt °F	400	410
fire pt °F	440	495
color	red - amber	lemon - orange
hard water	dispersible	soluble in high concentration
methanol	soluble	soluble
ethylene glycol	soluble in high conc.	soluble in high concentration

6. Solid Antislip Material

Fine silica powder, less than 1 micron, markedly increases sliding friction and has been used to increase railroad wheel/rail interaction. This material might produce some stabilization of snow surfaces by inhibiting the relative motion of snow granules. Because of its bulkiness, erosive effects (on machinery) and difficulty of handling no consideration was given to using it dry. If it should prove advantageous, it would be dispersed in a liquid phase probably in conjunction with one of the other methods, e.g., organo-metallic liquids, or the carrier liquid for the ultra thin film technique. Increased viscosity of the carrier fluid may complicate dissemination of the suspension.

7. <u>Low Expansion Foams</u> (approximately 7X volumetric expansion)

Low expansion foam was of interest in this application and appeared feasible if materials reactive at the low temperatures encountered in snow stabilization were available or can be developed readily.

In an application by a commercial firm[4] polyurethane foams were used at temperatures as low as -20°C. The major problem expected at lower temperatures is that the high viscosity of the reactants will interfere with mixing and dissemination.

In another commercial trial[5] polyurethane foams have been used to cover icebergs in the Arctic.

FIRL obtained two gallons of low viscosity reactants which were expected to be best suited for low temperature use.

8. <u>High Expansion Foam</u> (1000X volumetric expansion)

Low density foams with very large expansion ratios (> 1000 to 1) have been used for automatic fire fighting systems in aircraft. Investigation of commercially available foams of this type revealed that the liquids used are not effective at low temperature, and freezing point depressants that do not interfere with the bubble formation would be required.

9. <u>Fiber Bonding</u>: In this technique snow stabilization would be achieved by incorporating fibers into the surface to lock the loose flakes into a thin mat. Bonding would be accomplished by melting and refreezing. Heat would be applied either by dispersing preheated fibers or by heating in place using an exothermic reaction. For good logistics, it is necessary to get the maximum strengthening of the fiber reinforced

"crust" at the minimum weight and bulk of fibers to be transported. This implies relatively fine fibers of high strength. Composite theory indicates that materials such as steel and glass would be suitable as well as economical. These fibers should be of the order of 1/2 inch long and a few thousandths of an inch or less in diameter.

It was suspected that if such fibers were heated in the aircraft, for example in the engine exhaust, and sprinkled over the landing site that they would cool much too rapidly to be effective. The analytical expression for the cooling of the fibers is quite difficult to treat rigorously but is of the form

$$T_F = T_A + (T_F^{\circ} - T_A) \frac{1}{K} \chi \left(r, \frac{H}{k}\right) e^{-K\alpha t}$$

where

T_F is the temperature of a fiber at time t, radiating heat to the air

T_A is the air temperature

T_F° is the initial fiber temperature

K is the thermal diffusivity of the fiber

r is the radius of the fiber

Note that the thermal diffusivity K is:

$K = k/\rho c$

where

k = thermal conductivity

ρ = density

c = specific heat capacity

Therefore, the diffusivity and hence the cooling rate of the fiber is lowered by a low conductivity, high density and high specific heat. Therefore, glass would be expected to cool slower than steel because the lower conductivity and higher specific heat of glass more than compensates for its lower density.

10. Ultra Thin Films

Polymeric and colloidal particles have been used successfully in dust suppression and could be useful in stabilizing powdery snow. In particular, Dr. P. S. Francis of our Chemistry Department, has shown that regenerated films, cast from chopped ultra thin film (UTF) suspensions will stabilize soil against severe wind errosion, at a logistic advantage over conventional latexes. The basic problem in applying coatings of polymer latexes or UTF suspensions to the present problem was the low temperature. All commercial film-forming latexes are water-based and would freeze before the particles coalesced or the aqueous carrier evaporated. Alcohol based UTF suspensions were prepared at FIRL and were evaluated on snow. This work is included in the next section of this report.

11. Organo Metallic Heating in Situ

One of the most promising ways of heating and sintering snow was considered to be by the use of an organo-metallic liquid. The O.M. liquid would be sprayed on the snow surface to be stabilized. On contact with the snow the O.M. would react to liberate heat melting a snow layer which would then refreeze in the frozen slush crust. The O.M. materials

are logistically attractive because of the large amount of heat liberated per pound, ∿ 20,000 BTU/pound, and because the rate of heat evolution can be controlled so that the efficiency of snow heating and melting can be optimized. As a reference point, it was calculated that one pound of organo-metallic liquid can react and generate sufficient heat to melt enough snow to provide an ice layer 1/8 in. thick covering 35 sq. ft.

1.2.3 Laboratory Evaluation

1.2.3.1 Preparation of Snow and Testing Procedure

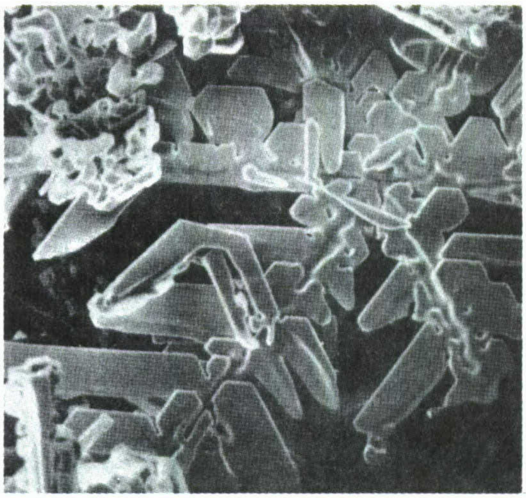
Snow was prepared by atomizing precooled distilled water into a 27 cu. ft. cool box at -40°F to -65°F. The "as deposited" snow was between 1/5 and 1/15 as dense as water, depending on the rate of snow production. The particles were quite fine (Fig. 1) and the entire bulk of deposited snow could be blown up into a "white out" condition by a brief blast of air from the 80 psi line.

The various liquids were deposited as a fine spray from an atomizer at a rate of 0.2 g/in^2 (9 oz/yd^2). Screening tests were conducted on fields of this artificial snow 10 sq. in. in area and 1/2 to 1 in. deep. The ultra thin films, fibers and foams were applied with appropriate dispensers. For the more promising materials lower concentrations and larger snow fields were used. During the screening tests the treated surfaces were evaluated by qualitatively determining their penetration resistance and mechanical integrity with a glass rod.

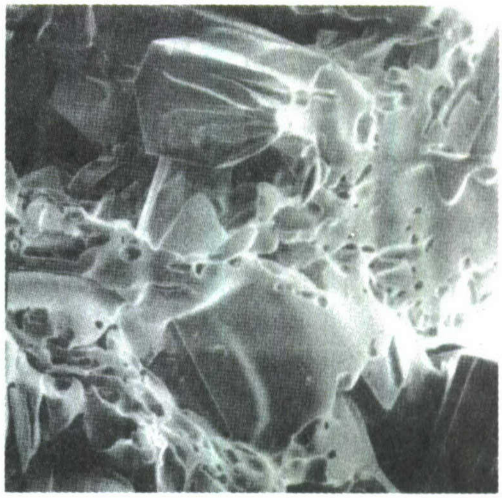
1.2.3.2 Candidate System Testing

The following paragraphs review the results of the laboratory

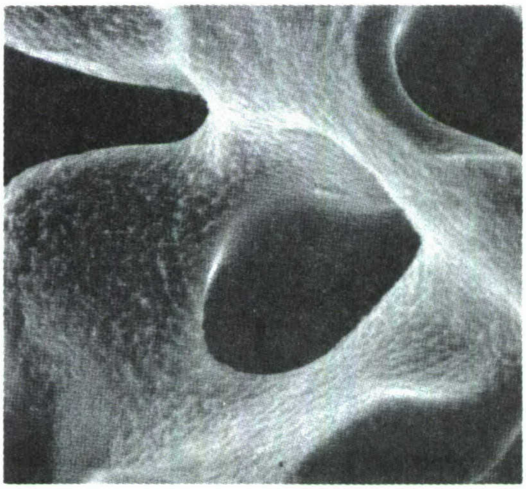
SNOW FLAKES



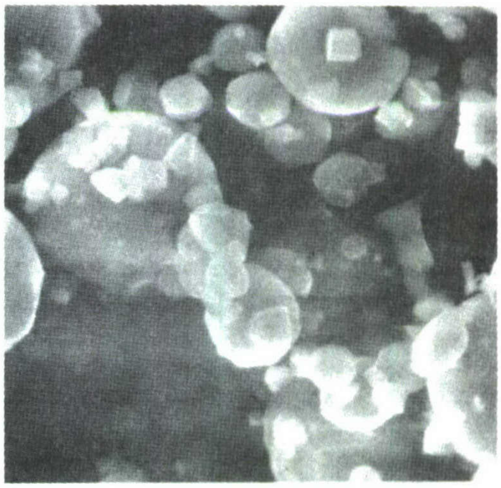
A. Freshly Fallen Snow 60X



B. Snow "Aged" 2 weeks 60X



C. 2-Day Old Snow Flake 600X



D. Artificial "Snow" Made in Cold Box at -25°C 1000 X

Scanning Electron Microscopy of Snow Flakes Using Liquid Nitrogen Cold Stage

(reduced to 77% in reproduction)

Figure 1

evaluation of the candidate snow stabilization methods discussed in Section 1.2.2. Each candidate method is discussed separately.

1. <u>Accelerated Sintering</u>

a. Antifreeze Sintering Agents

Of the candidate agents investigated, the most promising materials were the antifreeze sintering agents. A total of twenty-five different experiments were conducted using both methanol Table II and ethylene glycol/water Table III sintering agents. Methanol appears superior to the ethylene glycol/water system in promoting snow stabilization. When applied in the laboratory tests in concentrations as low as 2.8 oz./yd^2, significant snow stabilization was achieved almost immediately. The surface thus treated became stronger and harder with time <u>for at least 16 hours</u> after application.

An evaluation of resistance to blowing was conducted on a yard square snow surface of average depth 1 in., 16 hours after application of pure methanol at a concentration of 2.8 oz./sq. yd. A sustained air blast of 30 mph at a 45° angle of attack caused large chunks of the stabilized surface to blow away after about 30 sec. exposure to the blast. It should be noted that the air of the blast was at room temperature so that warming and possible melting preceded loss of the surface.

b. Fluoride Doping

A series of tests were conducted (Tests #52 through 57) Table III with various concentrations of fluoride in solutions since this material was considered the most potent potential dopant. Detectable effects of accelerated sintering were demonstrated but the rate of surface hardening and

SNOW SURFACE STABILIZATION

Methanol Tests

TABLE II

#	Material Used	Quantity Used	Surface Area of Snow	oz/yd^2	Results
1	Methanol	$\approx$ 2 grams	10 in^2	9.1	Melted most of the snow in the tray; formed slush
2	Methanol	$\approx$ 2 grams	10 in^2	9.1	Melted most of snow in tray; formed slushy layer
3	Methanol	$\approx$ 2 grams	10 in^2	9.1	Melted entire tray of snow (formed slush)
4	Methanol	1.6 grams	10 in^2	7.3	Melted snow in tray (formed slush)
5	Methanol	24 grams	120 in^2	9.1	Melts snow - formed slush
6	Methanol	24 grams	120 in^2	9.1	Almost 1/2 the snow melted
7	Methanol	24 grams	120 in^2	9.1	Specimen was 3 days old when tested with air blast withstood blast much in excess of 30 m.p.h. for 5 sec. before breaking into large chunks
8	Methanol	12 grams	120 in^2	4.6	Snow melted, but not as much as at 9 oz/yd.; still appears very adequate
9	Methanol	80 g	9 ft^2	2.8	Methanol applied with fine spray (portable sprayer). Crust formed over all of surface 1-10 min. Two large ($\sim$1 sq. ft.) slush areas formed. Loose snow clinging to walls was contacted by fine methanol mist. This snow fell to floor during 10 min. following application. After 16 hours slushy areas larger and hardening. Sustained air blast, broke out 1/4 ft^2 chunk as solid piece (16 hrs. after application).

TABLE II - continued

#	Material Used	Quantity Used	Surface Area of Snow	oz/yd^2	Results
10	75% methanol 25% ethylene glycol	2 grams	10 in^2	9.1	Almost no melting, crusting or other observed effect on the snow
11	50% methanol 50% ethylene glycol	2 grams	10 in^2	9.1	Very little observed effect upon the snow
12	25% methanol 75% ethylene glycol	2 grams	10 in^2	9.1	Very little observed effect upon the snow
13	37-1/2% water 37-1/2% ethylene glycol 25% methanol	2 grams	10 in^2	9.1	Very little observed effect upon the snow
14	25% water 25% ethylene-glycol 50% methanol	2 grams	10 in^2	9.1	Snow partially melted
15	12-1/2% water 12-1/2% ethylene glycol 75% methanol	2 grams	10 in^2	9.1	Snow melted; slush formed;
16	60% ethylene glycol 40% methanol	2 grams	10 in^2	9.1	Less effective than pure methanol. Solution almost solid at -40°F
17	60% ethylene glycol 10% water 30% methanol	2 grams	10 in^2	9.1	Promoted bulk sintering.
18	25% CCl_4 + 75% methanol (possible flame suppression system)	2 grams	10 in^2	9.1	Not as good as pure methanol; mixture separated
19	5% CCl_4 + 95% methanol (possible flame suppression system)	2 grams	10 in^2	9.1	Worked as well as pure methanol; CCl_4 appeared to mix with methanol

SNOW SURFACE STABILIZATION

ETHYLENE GLYCOL/WATER AND FLUORIDE DOPING TESTS

TABLE III

#	Material Used	Quantity Used	Surface Area of Snow	oz/yd^2	Results
20	Water	$\approx$ 2 grams	10 in^2	9.1	Formed crust of ice on snow surface
21	60% ethylene glycol 40% water	$\approx$ 2 grams	10 in^2	9.1	Melted snow to a small degree
22	60% ethylene glycol 40% water	$\approx$ 2 grams	10 in^2	9.1	Made snow very sticky (applied cold)
23	60% ethylene glycol 40% water	3 grams	10 in^2	1.4	Difficult to apply cold (very thick) little effect to snow (slightly sticky)
24	50% glycerine 50% ethylene glycol	Solution too thick to spray at room temp : 70°F			
25	95% ethylene glycol 5% methylene chloride	2 grams	10 in^2	9.1	Causes extensive crusting; too thick to apply at -40°F

SEE TABLE I FOR MIXTURES OF ETHYLENE GLYCOL AND METHANOL.

#	Material Used	Quantity Used	Surface Area of Snow	oz/yd^2	Results
52	1% NH_4 FHF	2 grams	10 in^2	9	No detectable effect.
53	.1% NH_4 FHF	2 grams	10 in^2	9	No detectable effect.
54	.01% NH_4 FHF	2 grams	10 in^2	9	No detectable effect.
55	1% NH_4 FHF	converted to snow			This material sintered much more rapidly than virgin snow but not nearly as solidly as methanol treated snow.
56	.1% NH_4 FHF	converted to snow			Same as 55 but less pronounced.
57	.01% NH_4 FHF	converted to snow			Slightly accelerated sintering.

SNOW SURFACE STABILIZATION

Surfactants

TABLE IV

#	Material Used	Quantity Used	Surface Area of Snow	oz/yd^2	Results
26	20g."Span 20" dissolved in 80cc methylene chloride	$\approx$ 2 grams	10 in^2	9.1	Formed slight film; did not appear to bond to snow.
27	20g."Tween 21" dissolved in 80cc methylene chloride	$\approx$ 2 grams	10 in^2	9.1	Formed slight film; did not appear to bond to snow.
28	50% "Tween 21" 50% ethanol	$\approx$ 2 grams	10 in^2	9.1	Formed tacky film on surface of snow; did not bond to snow
29	20% "Span 20" 30% ethanol 50% water	$\approx$ 2 grams	10 in^2	9.1	Snow surface became slightly tacky.
30	2% "Span 20" 64% ethanol 34% water	$\approx$ 2 grams	10 in^2	9.1	Surface became very sticky (may have melted snow)
31	2% "Tween 21" 64% ethanol 34% water	$\approx$ 2 grams	10 in^2	9.1	Surface became very sticky (may have melted snow)
32	20% "Tween 21" 20% ethanol 30% water	$\approx$ 2 grams	10 in^2	9.1	Surface became slightly sticky (snow may have melted)
33	5% "Span 20" 15% "Tween 21" 30% ethanol 50% water	$\approx$ 2 grams	10 in^2	9.1	Formed a plastic layer over surface of snow; appeared to bond to snow
34	20% "Span 20" 30% ethanol 50% water	1.7 gram	10 in^2	7.8	Very friable (formed plastic film on snow)
35	5% "Span 20" 15% "Tween 21" 30% ethanol 50% water	1.8 gram	10 in^2	8.2	Intermediate friability between Span 20 and Tween 21
36	20% "Tween 21" 30% ethanol	1 gram	10 in^2	4.6	Stronger than Span 20 film
58	Octanol	$\approx$ 2 grams	10 in^2	9.1	Slight stabilization of surface after 54 hrs. (applied warm)

the strength of the surfaces produced <u>was so low as indicated</u> that <u>no</u> doping technique will be likely to satisfy the requirements of the project.

2. Water

Water by itself was not evaluated in the laboratory phase since the disadvantages which were apparent from even a cursory paper study, were such so as to eliminate it from further consideration. It should be noted that the deleterious effect of increasing the water content in ethylene glycol/water mixtures corroberate this conclusion.

3. Surface Active Agents

a. Octanol

Experimentation with octanol indicated that the approach was not suitable for this particular application. (Table IV) Although slight stabilization of snow was noted, several days of exposure to octanol were required for this to occur. The octanol stabilized snow was readily blown by low velocity winds.

b. "Span" and "Tween"

"Span" and "Tween" both separately and in combination were evaluated against powder snow in the test chamber (Table IV). Solvents used with these agents included methylene chloride, ethanol, methanol and/or water. Results were promising in that several of the combinations appeared to form a film and bond the snow particles together.

Differentiation between the effect contributed by the Span/Tween component and the solvent component was not attempted.

c. Solid Antislip Materials

Since it had been decided that these materials could only be used in conjunction with another material, e.g. a liquid vehicle, testing was postponed until the optimum system had been identified. At that time a determination can be made as to whether any further improvement can be expected from adding these materials.

4. Low Expansion Foams

Several low expansion foams were evaluated both on snow and other surfaces (Table V). The major problem encountered was incomplete expansion of the foam at low temperature (0 and -40°C). When the unreacted foam was removed from the test chamber and allowed to warm, the material began to foam. The foams were of the polyurethane type.

5. High Expansion Foams

The high expansion foams were rejected because of their very low intrinsic strength and the unavailability of suitable systems for low temperature expansion and application. Very low wind velocities (< 5 mph) would blow the foam off the snow surface.

6. Ultra Thin Film

Laboratory tests with ultra thin films in hexane solutions were promising in that substantial surface films were formed on the snow surface (Table V). Pre-cooling the UTF/hexane solution to -40°C however, resulted in significantly poorer film being formed on the snow surface (Reference Tests 42 and 43). Considerable development effort would be required to produce an acceptable UTF method of snow stabilization.

SNOW SURFACE STABILIZATION

Foams and Films

TABLE V

#	Material Used	Quantity Used	Surface Area of Snow	oz/yd^2	Results
37	commercial urethane foam	undetermined	$10\ in^2$	?	Formed thick layer of foam on snow; surface in contact with snow did not react
38	Polyurethane foam	undetermined	$10\ in^2$	?	Ingredients did not react properly, foam not formed
39	Iso-Cyanate urethane foam (commercial)	$\approx .3\ gram/in^2$	$120\ in^2$	15.1	Tested on snow at -40°F after 10 min. 3/64" layer remained unreacted in contact with snow. Same after 30 min. When warmed to 70°C unreacted layer foamed.
40	commercial Iso-Cyanate urethane foam	$\approx .33\ grams/in^2$		15.1	Tested on cat litter; adhered to litter; foam began to lift when air jet was directed from 45° at $\sim$ 20 mph
41	"Silly-String" commercial (play toy) foam dispenser that makes foam filaments about 1/8" dia.	-	-		Produced very weak string of foam; did not adhere to cat litter; blew away under 5 mph air jet, probably completely reacted before contact is made with substrate
42	P.V.C./UTF (ultra thin film) in Hexane	10 ml	$10\ in^2$	$\sim 1\ qt/yd^2$	Good crust formed in 10 min; deposited by drops from a flask.
43	P.V.C.(UTF) in Hexane precooled to -40	10 ml	$10\ in^2$	$\sim 1\ qt/yd^2$	Poor crust this time (not hard) deposited by drops from a flask

7. Fibers

Before initiating the laboratory experimentation, an analysis was conducted to review the effect of geometry and material on heat loss and utilization. In this analysis the fiber was considered to be an infinite cylinder i.e., all the heat was lost in the radial direction. As the radius is decreased (surface to volume ratio increased) the cooling rate increases rapidly. Order of magnitude estimates for steel fibers indicate that cooling from the melting point to ambient temperatures occurs in seconds for fibers larger than 0.040 in. but occurs in milliseconds for fibers less than 0.005 in. Fibers as large as 0.040 in. are inconsistent with the mechanical and logistic requirements of this approach.

Analysis of the efficiency of snow melting by hot fibers once they are in contact with the snow indicated that high conductivity and small diameter were desirable. Again the small diameter was required in order to maximize the number of reinforcement points in the crust for a given pay load.

Figure 2 shows the relative melting efficiency of steel and glass fibers. The superiority of the steel is evident. This, of course, is due to its superior conductivity. The conclusion to be drawn from these analyses is that the fiber characteristics that favor good melting and composite formation with snow are precisely the opposite of the characteristics required to minimize cooling during sprinkling.

An experiment was conducted to confirm the cooling behavior

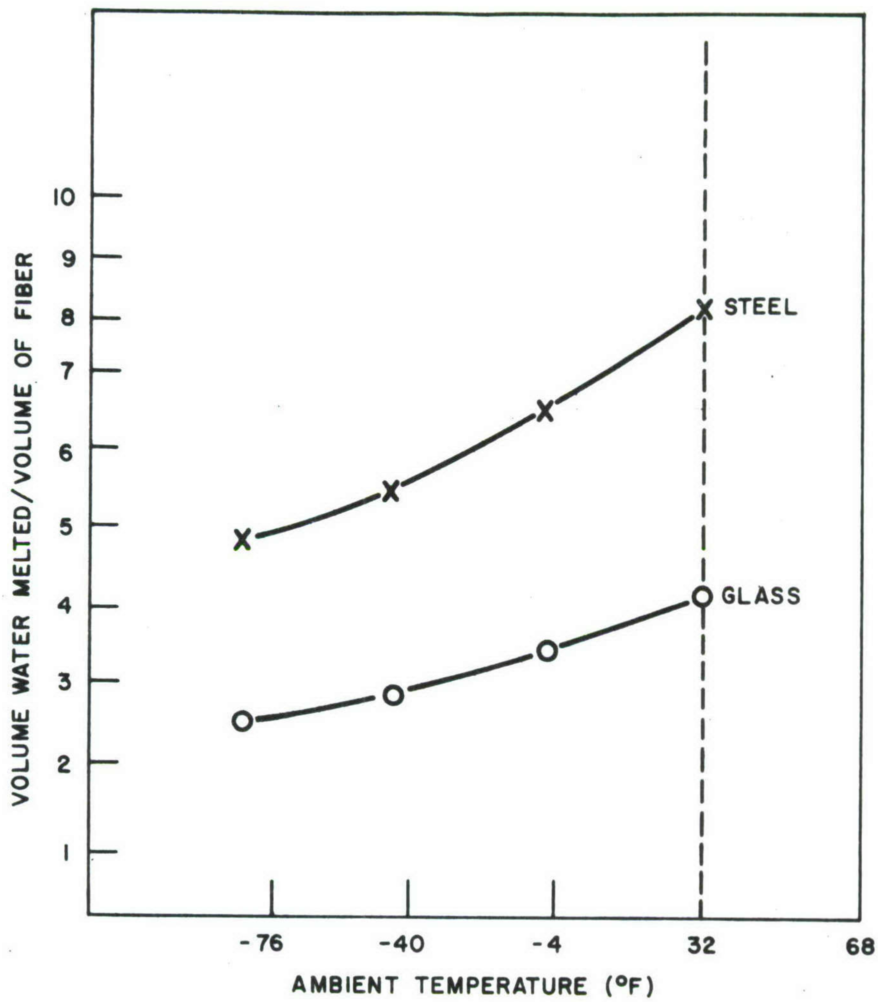


Figure 2. Melting Efficiency of Glass and Steel Fibers

predicted by the analytical treatment because a quantitative evaluation of the theory would have taken much longer than the experimental check.

The experiment consisted of allowing heated fibers to fall through still air at ambient temperatures and determining the cooling rate. The fibers consisted of thin aluminized glass filaments, thick glass fibers and steel wire. All were about 1/2 in. long and were heated to 660°F. This was chosen as a practical temperature that might be obtained by heating in the engine exhaust. They were then dropped from elevations of 3 and 7 feet onto thin polyethylene sheet. It was determined that fibers warmer than 145°F would stick to the sheet.

The rate of fall of the fibers was also determined and from this the rate of cooling could be determined. The details of the experiment and the results are presented in Table VI.

TABLE VI

COOLING RATE OF FALLING FIBERS

Fiber	Diam. (in.)	Velocity of Fall (ft/sec)	Drop Ht. (ft.)	Sticking	Cooling Rate (°F/sec)
glass	0.014	6.2	3	yes	1000
			7	no	>1000
glass	0.001	1.4	3	no	>1000
			7	no	>1000
steel	0.004	5.2	3	no	>1000
			7	no	>1000

As expected the larger glass fibers had the lowest cooling rate. It is evident that only relatively thick glass or other low conductivity fibers have low enough cooling rates to offer any hope of permitting dispersion over even small distances.

In order to fully explore the potential of fiber matting however, 0.015 in. diameter glass fibers heated to about 600°F were

dropped directly on the surface of artificial snow fields from elevations of only a few inches (Table VI). A major difficulty arose in that only a few fibers landed flat on the snow surface; the rest tended to stick into the snow at various angles. All of the fibers caused local melting of the snow, but the fibers did not stick to the snow and ice after refreezing had occurred.

8. Organometallic Heating

For snow stabilization purposes, the desired organometallic compound should have very low reactivity with atmospheric oxygen, react promptly with the snow particles generating sufficient heat to melt the particles, not require diluents to reduce calorific value, and be safe to handle. After consultation with the primary manufacturers of organometallic compounds, it was concluded that no "off-the-shelf" compound exists which meets most of the above requirements.

"Off-the-shelf" organometallic compounds are too highly reactive with air and moisture to be used without extensive dilution with saturated petroleum oils and fire retardants. Maximum concentration or organometallics in suggested formulations were 30%. Instead of the hoped for 18,000 to 22,000 BTU per pound of pure organometallic compounds, only 5,000 to 7,000 BTU's per pound were available in the reduced activity formulations. On this basis, the use of organometallic agents to stabilize the snow was not pursued further in this phase of the program.

Approximately one and a half months after this phase was completed FIRL was able to obtain an organometallic compound specially prepared

SNOW SURFACE STABILIZATION

Miscellaneous (Organic Solvents, Fibers and Dopants)

TABLE VII

#	Material Used	Quantity Used	Surface Area of Snow	oz/yd^2	Results
44	Diethylene Glycol Monopropyl ether	$\approx$ 2 grams	10 in^2	9.1	Snow surface became slightly tacky
45	Diethylene glycol Monoethyl ether	$\approx$ 2 grams	10 in^2	9.1	Snow surface became slightly tacky
46	Acetone	$\approx$ 2 grams	10 in^2	9.1	Made snow surface slightly sticky
47	Isopropyle Alcohol	2 grams	10 in^2	9.1	Same effect as methanol; but less vol. of snow involved
48	95% glycerine 5% methylene chloride	too thick at room temperature to apply			
49	Glycerine	became too thick to spray			
50	50% glycerine 50% water	2 grams	10 in^2	9.1	Solid at -40°; good room temp. consistency, very little effect on snow
51	Glass fibers .010 to .14" dia. x 1/2" long 660°F, dropped 2"	25 fibers	10 in^2	(.16)	Slight melting, fibers did not felt, no significant adherence of snow to fibers

for this program. The compound was *tri-n-octyl aluminum*. Although the laboratory phase of the program was completed, it was decided to evaluate the material in the laboratory chamber against simulated snow.

Approximately 5 grams of tri-n-octyl aluminum was applied by pipette to a 12 inch x 12 inch tray of laboratory snow. Considerable smoke was generated by the reaction of the organometallic agent with the air. In addition a vigorous, splattering occurred when the drops touched the snow surface. Observation of the snow surface indicated that considerable sintering did occur. It was felt, however, that this particular compound was still too reactive and that aluminum alkyl compound with a higher molecular weight might be more suitable for this application.

Discussion and Conclusion

The following discussion and conclusions can be made regarding the results of the laboratory experiments:

1. Accelerated Sintering

Both the methanol and ethylene glycol/water treatments in low concentration(2.8 oz./yd) produced surfaces that were very resistant to blowing. The methanol was slightly superior to the ethylene glycol/water system.

Treatment with solutions containing fluoride ions produces only marginal effects and cannot be considered a good candidate system.

2. Water

Water was eliminated because of its logistic inefficiency.

3. Surface Active Agents

The most promising formula developed for the span/tween system was:

5% Span 20
15% Tween 21
30% Ethanol
50% Water

4. Low Expansion Foams

Low Expansion Foams of the polyurethane type which are satisfactorily reactive at required temperatures are either unavailable or have not been developed.

5. High Expansion Foams

High Expansion Foams were not evaluated in the laboratory because systems suitable for use at the required low temperatures are not available.

6. Ultra Thin Films

Ultra Thin Films were successfully deposited from hexane to snow surfaces; however, it appears that considerable development effort will be required to produce a practical system based on this concept.

7. Fibers

On the basis of both laboratory evaluation and theoretical considerations, it has been determined that the fiber approach is unsuitable for snow stabilization within the boundary conditions outlined in the work scope of this assignment. Factors influencing this

determination include:

a. It will be difficult to disperse fibers either from the aircraft or from containers on the ground so that they fall flat on the surface of the snow.

b. It has been demonstrated that hot fibers do not bond well to the snow on refreezing.

c. It will be difficult to heat the fibers. The fibers cannot be dispersed hot even over short distances because their rate of settling in the air is so slow that they always cool off long before they reach the snow.

8. Organometallic Heating

Since good sintering of the snow surfaces was produced in the organometallic test, this method is considered to be potentially useful. Exploitation of this potential, however, depends on developing a less reactive compound such as a higher molecular weight aluminum alkyl.

1.2.3.3 Summary of Most Promising Results

Based on the laboratory evaluation, the most promising systems were (a) methanol, (b) 75% methanol, 12 1/2% ethylene glycol, 12 1/2% water, (c) 60/40 blend of ethylene glycol and water, (d) 5% Span 20, 15% Tween 21, 30% ethanol, 50% water, (e) isocyanate foam, and (f) UTF in hexane. Table VIII is a listing of these materials.

SUMMARY OF MOST PROMISING RESULTS

TABLE VIII

#	Material	oz/yd^2	Results
9	Methanol	2.8	Best of all tests; withstood ∿ 30 mph with no white out.
15	75% Methanol 12 1/2% ethylene glycol 12 1/2% water	9.1	Very similar to methanol at same dose level.
22	60% ethylene glycol 40% water	9.1	Similar to methanol but about one-half as effective.
33	5% "Span 20" 15% "Tween 21" 30% Ethanol 50% Water	9.1	Best of surfactants Thin film formed. Snow particles adherent
39	"Iso Cyanate" Urethane Foam	∿15	Unreacted layer ∿ 3/64" Very strong material
42/43	UTF in Hexane	∿ 1 qt/yd	Cohesive films formed readily on snow.

1.3 Phase II Field Evaluation

1.3.1 Preliminary Field Tests

Three preliminary field tests were carried out in the Philadelphia area.

First Preliminary Field Test

In this test Methanol was sprayed on snow that consisted of 1/2 inch aged (2 days) (Fig. 2) fluff on 2 inches of frozen ice/snow. The ambient temperature was 8°F. In less than 5 minutes the surface had become sufficiently hard that a spatula could be slid over it without disturbing it while the adjacent snow was readily penetrated. After an additional three days during which the temperature never exceeded 20°F the treated surface remained hard. Note that this area was 8 ft. by 2 ft. and completely shaded from the sun. The original snow density was 1/8 that of water.

This was the first practical use of methanol (out of doors) and encouraged us to proceed to the second, more controlled field test.

Second Preliminary Field Test

In the second preliminary test both methanol and 60% ethylene glycol/40% water solutions were applied. The spray device used for all subsequent field tests was used and both solutions were applied as fine and as coarse sprays at several application rates, Table IX The solutions were doped with black ink so that uniformity and extent of coverage could be readily assessed during application. A three to five mile/hr breeze was blowing and the air temperature was 23°F. The snow surface

was 2°F below in temperature. A very light, though moist, snow was falling. The relative humidity appeared to be quite high. The time was just before dusk and the sky was heavily overcast. There were no shadows.

TABLE IX

APPLICATION RATES

Spray Droplet Size	Methanol	Ethyleneglycol (60%)/Water (40%)
Fine	3.2 oz/yd	3.2 oz/yd
	13 oz/yd	
Coarse	7.2 oz/yd	7.2 oz/yd
	14 oz/yd	14 oz/yd

The principle conclusions of this test were:

1. The uniformity of coverage was better with the fine spray than the coarse but the coarse spray still produced acceptable results.

2. There was only minor difficulty in compensating for blowing of the fine spray at the wind speeds encountered.

3. The methanol treated areas achieved a blow resistant slushy character in 1 to 3 minutes after application while the ethylene glycol/water treated areas took about twice as long and were not quite as resistant to blowing.

In summary the application technique appeared adequate for more elaborate field test and both solutions tried appeared to be effective though methanol was somewhat superior.

Third Field Test

In the third field test commercial polyurethane foam was deposited in a 1.5 sq. yd. surface of crushed ice outdoors. The ambient temperature was 15°F and the test was conducted in the shade. The reactants were dispensed from pressurized cylinders and mixed a fraction of second before application in a mixer-dispenser nozzle. The contents of the cans had not cooled appreciably below room temperature by the time of application and flowed readily through the nozzle and onto the ice.

The foam was dispensed from about 18 inches above the ice in a cross hatched pattern of 2 inch strips which ultimately covered approximately 2/3 of the ice surface. Only small patches of ice were left exposed through the intersticies.

The purpose of this test was to observe the reaction behavior (foaming) of the reactants at depressed temperature in contact with ice (i.e. a snow simulant).

The foam generated sensible heat and appeared to be unaffected by the low temperatures. A thin layer about 1/16 to 1/8 in. thick directly in contact with the ice remained unreacted. This was considered inconsequential and it was decided to include a limited evaluation of those foams in the full scale field tests.

1.3.2 Watertown, N.Y. Test

1.3.2.1 Site Selection

A review of the climatic conditions expected in the eastern U.S. indicated that the area around Watertown, N.Y. offered the best chance for appreciable snow falls during the months of February and March. Watertown is located on the northeast tip of Lake Ontario and is considered a "snow belt" region. It is about fifteen miles from the St. Lawrence River. Camp Drum, an Army facility, is also located near Watertown.

Another major factor in selecting this site for the field tests was the accessibility of major highways in the area. This was considered important since all test materials would need to be transported to the site by truck. The relative nearness of Watertown to Philadelphia enabled the test team to wait for an approaching storm system before traveling to the site. Adequate facilities were also available in Watertown.

1.3.2.2 Evaluation Techniques

To evaluate the effectiveness of the candidate snow stabilization systems, two basic test procedures were selected. The first test evaluates load bearing strength of the snow and the second evaluates blowability of the snow.

To evaluate the load bearing strength of the treated and untreated snows, a simple device was built consisting of a series of weighted discs which are placed on a 7" diameter plywood disc positioned on the selected snow area. When the load bearing strength of the snow is exceeded, a fracture of the snow surface occurs. Generally, untreated snow has load

bearing strength of less than ten pounds per square foot whereas some treated snow had load bearing strengths over 100 pounds per square foot.

A Mitey Mite Blower (Model M-18) was used to simulate the helicopter down blast and determine the relative stability of the treated snow surface to resist blowing. Air speed as a function of nozzle distance above ground was measured. Table X is a chart listing air speed of the blower as a function of the length of the nozzle above the ground. Untreated snow produced "white out" conditions when the blower was positioned 14 inches above the snow ($<$40 mph wind speed), whereas some of the treated snows did not produce particles even when the nozzle was within 2 inches of the treated snow surface. ($>$ 60 mph wind speed).

TABLE X

Height of Nozzle Above Ground (inches)	Air Speed (mph)
2	> 60
6	60
12	50
14	40

In addition to the above tests, other routine data was also recorded. This included snow density, temperature, humidity, wind direction/velocity and related meteorological conditions.

1.3.2.3 First Field Test at Watertown

On Friday, February 12, 1971, weather forecasts predicted a major storm system would hit the Watertown, N.Y. area in about five days. The test team assembled their gear and left for the test site on Monday, February 15, 1971. The test team arrived during the final stages of a snow storm which deposited approximately twelve inches of new snow on an existing base of 24 to 30 inches of packed snow.

At Camp Drum, two test sites were selected. The first site was on the runways of the Camp Drum airport which is closed to air traffic from mid November to April 15th. The second site was located approximately a mile from the first site but in a lightly wooded area where the winds were less severe. Typical test scenes are shown in Figure 3.

A total of eight large area (> 30 $ft.^2$) tests were conducted during this first field test. Two tests were conducted at the airport site and six were conducted at the lightly wooded site. Pertinent data on these eight tests are presented in Table XI. With respect to the results of the first field tests, the following comments appear in order:

Snow Density: The difference in snow density for the untreated snow between the airfield sample and the wooded area sample is probably caused by the wind and sun exposure. At the airfield site, wind blowing across the runway had a pronounced tendency to cause crusting of the snow. The crusted surface was removed prior to the tests. The wooded site was protected to a degree from the wind and the direct rays of the sun and, therefore, no appreciable crusting of the snow occurred during the days of testing.

Measuring Snow Depth

Spraying Agent on Snow

Blowing Treated Snow

Measuring Load Bearing Strength

Figure 3. Field Tests at Watertown, N.Y.

Table XI
FIRST FIELD TEST

Test No.	Agent	Application Concentration	Spray Type	Location	Metrological Data	Evaluation: Snow Density	Evaluation: Snow Load Bearing Strength	Evaluation: Blower Effect
-	Untreated Snow	-	-	Airfield	Wind sp 3 mph Air Temp +18°F Snow Temp 8°F	.20g/cc	16#/ft^2	Snow began blowing when blower was within 2 ft.
1	Methanol	1 oz/ft^2	Fine	Airfield	Wind sp 3 mph Air Temp +18°F Snow Temp 8°F	-	64#/ft^2	After 1/2 hr, no blowing at 2-4" above snow surface
2	Methanol	1 oz/ft^2	Coarse	Airfield	Wind sp 3 mph Air Temp +18°F Snow Temp 8°F	-	54#/ft^2	Blower blew up chunks of snow at 6-8"
-	Untreated Snow	-	-	Wooded Area	Wind sp 3 mph Air Temp +22°F Snow Temp 20°F Humidity 65%	.12g/cc	7#/ft^2	Snow began blowing when blower was within 3 ft. of surface
3	Methanol	.5 oz/ft^2	Fine	Wooded Area	Wind sp 3 mph Air Temp +22°F Snow Temp 20°F Humidity 65%	-	135#/ft^2	No blowing until blower was within 1" of surface
4	Methanol	.3 oz/ft^2	Fine	Wooded Area	Wind sp 3 mph Air Temp +22°F Snow Temp 20°F Humidity 65%	-	105#/ft^2	No blowing until blower was within 2" of surface
5	Ethylene Glycol/water	.5 oz/ft^2	Fine	Wooded Area	Wind sp 3 mph Air Temp +22°F Snow Temp 20°F Humidity 65%	-	70#/ft^2	Snow blew off surface when blower was 12" above surface
6	Ethylene Glycol/ water (60-40)	.3 oz/ft^2	Fine	Wooded Area	Wind sp 3 mph Air Temp +22°F Snow Temp 20°F Humidity 65%	-	90#/ft^2	Snow blew off surface when blower was within 18" of surface
7	Ethylene Glycol	1.0 oz/ft	Coarse	Wooded Area	Wind sp 3 mph Air Temp +22°F Snow Temp 20°F Humidity 65%	-	70#/ft^2	Snow blew off surface when blower was within 18" of surface
8	Methanol	1.0 oz/ft	Coarse	Wooded Area	Wind sp 3 mph Air Temp +22°F Snow Temp 20°F Humidity 65%	-	135#/ft^2	No blowing of snow until blower was within 2" of surface

Load Bearing Strength: Untreated snow had a load bearing strength when measured by the FIRL technique of from 7 to 16 lb/ft^2 depending on site location. The treatment by the various agents increased the load bearing strength of the snow to ranges from 54 lb/ft^2 to 135 lb/ft^2 depending on type of agent and condition of the snow before treatment. It is significant that the lightest, fluffiest snow (wooded area site) which originally had a load bearing strength of only 7 lb/ft^2, after treatment with methanol at a concentration of from 0.5 to 1.0 $oz./ft^2$, had a laod bearing strength of approximately 135 lb/ft^2.

Blower Effect: The methanol agent had the greatest effect in reducing the tendency of snow to blow around when subjected to the relatively high velocity air blasts generated by the Mitey Mite blower. Whereas untreated snow was blown when the blower was 2 to 3 feet from the surface, after treatment with methanol, the blower had to be positioned within 1 to 2 inches before blowing would occur. As can be seen from the chart comparing the velocity of the Mitey Mite air blast to height above the surface, this means that wind speeds in access of 60 miles per hour are necessary for methanol treated snow to be blown around.

1.3.2.4 Second Field Test at Watertown, N.Y.

On February 19, the weather at Watertown changed. Temperatures rose into the mid-forties and it was decided to break camp until suitable climatic conditions returned. The weather remained unsuitable for test purposes until February 26th when the five-day forecast indicated a

severe storm system would probably hit Watertown in early March. The test team arrived at Watertown on March 1, 1971.

A severe snowstorm hit the area at noon on March 3rd and snow continued to fall until late in the evening of the 4th. A total snowfall of between 30 and 36 inches accumulated. The snowfall was accompanied by high winds ($>$ 30 mph) with the result that the snow was subjected to a high degree of mechanical working. This rendered it useless for our purposes since the snow was very dense (.35 g/cc) and of a very coarse texture.

Since the weather forecast for the next week was for temperatures in the upper forties, a conference was held with the Technical Supervisor to determine the next step. It was decided to abort the second field test since (a) the weather outlook was unfavorable, and (b) chances for a change in weather with a suitable snowfall appeared dubious for the balance of the winter season at Watertown. In retrospect, it should be observed that no appreciable snowfall has occurred since the date of the second field test.

2. CONCLUSION

As a result of the snow stabilization program conducted under Task Assignments 3 and 6 of Contract DAAD05-70-C-0389, the following conclusions may be made.

1. Light, fresh snow can be stabilized by the application of suitable chemical agents. Snow surfaces treated with methanol in concentrations as low as 1/4 ounce per square foot did not blow away when subjected to simulated helicopter downdrafts of up to 60 miles per hour. In addition, the load bearing strength of the untreated snow (7 lbs/ft^2) was increased to approximately 135 lb/ft^2 after treatment with suitable stabilization agents. It is, therefore, possible that the load bearing capacity of snow can be increased by such treatment to better support aircraft equipped for arctic conditions.

2. Of the agents evaluated, methanol was found to be the most effective material in achieving snow stabilization as well as the most effective of the agents in increasing the load bearing strength of the snow.

3. Other agents that were effective as snow stabilization materials were ethylene glycol/water and organometallic compounds. Foams and surface active agents such as "spans" and "tweens" also hold promise but additional R & D will be required to make these materials practical.

3. RECOMMENDATIONS

1. Since tests to date (including field tests) have been with relatively small treated snow areas (maximum 100 ft^2) and simulated helicopter down drafts, it is recommended that additional testing be conducted using large test areas and actual helicopter down drafts. Preferably, a base camp should be set up and the tests conducted during late November 1971 through late February 1972 to take advantage of optimum snow characteristics.

2. Since Methanol is the most promising agent encountered to date, a program should be initiated to determine if improvements can be made to the system. This would include additives to decrease flammability as well as additives to optimize stabilization characteristics.

3. Since at the present time the agents are disseminated from hand operated sprayer cans, it is recommended that a dissemination method be developed to shorten the application time (during the summer and fall of 1971), reduce the necessary manpower, and improve dispersion uniformity. The present system while suitable for small test areas, would be unsuitable for large area testing of a size suitable for actual helicopter operation.

4. In addition to the methanol system, other promising systems should be further investigated. These systems include non-flammable solvent systems similar to methanol, other antifreeze type solutions, high molecular weight aluminum alkyl type organometallic compounds and low temperature reactive polyurethane foams. Laboratory evaluation similar to that performed on this contract would be of some value, followed by extension to field evaluations as appropriate.

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* These communications were of a purely informational character and their inclusion in this report as references in no way implies indorsement or other recommendation of the commercial products involved by the sponsor or by the contractor.

APPENDIX A

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13. ABSTRACT

This report describes the result of a feasibility study to investigate surface stabilization of snow by chemical treatment to eliminate reduced visibility created by helicopter down wash on landing and take-off. Of the candidate methods evaluated, sintering of the snow by methanol appeared the most promising method. Polyurethane foam and snow-reactive metal aklyls, while promising, would require more development work.